Name: ______________________________ (   )   Class: 24 / ______

ANDERSON SERANGOON JUNIOR COLLEGE

2024 JC2 Preliminary Examination

PHYSICS Higher 2 — 9749/02

Paper 2 Structured Questions — **Tuesday 10 September 2024**

2 hours

Candidates answer on the Question Paper.
No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your name, class index number and class in the spaces at the top of this page.
Write in dark blue or black pen on both sides of the paper.
You may use an HB pencil for any diagrams or graphs.
Do not use staples, paper clips, glue or correction fluid.

The use of an approved scientific calculator is expected, where appropriate.
Answer **all** questions.

The number of marks is given in brackets [ ] at the end of each question or part question.

For Examiner's Use	
Paper 2 (80 marks)	
1	
2	
3	
4	
5	
6	
7	
8	
Deductions	
Total	

This document consists of **23** printed pages and **1** blank page.

Data

speed of light in free space	$c = 3.00 \times 10^{8}$ m s^{-1}
permeability of free space	$\mu_0 = 4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-12}$ F m^{-1}
	$(1/(36\pi)) \times 10^{-9}$ F m^{-1}
elementary charge	$e = 1.60 \times 10^{-19}$ C
the Planck constant	$h = 6.63 \times 10^{-34}$ J s
unified atomic mass constant	$u = 1.66 \times 10^{-27}$ kg
rest mass of electron	$m_e = 9.11 \times 10^{-31}$ kg
rest mass of proton	$m_p = 1.67 \times 10^{-27}$ kg
molar gas constant	$R = 8.31$ J K^{-1} mol^{-1}
the Avogadro constant	$N_A = 6.02 \times 10^{23}$ mol^{-1}
the Boltzmann constant	$k = 1.38 \times 10^{-23}$ J K^{-1}
gravitational constant	$G = 6.67 \times 10^{-11}$ N m^{2} kg^{-2}
acceleration of free fall	$g = 9.81$ m s^{-2}

Formulae

uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$
	$v^2 = u^2 + 2as$
work done on/by a gas	$W = p\Delta V$
hydrostatic pressure	$p = \rho gh$
gravitational potential	$\phi = -\frac{Gm}{r}$
temperature	$T/\text{K} = T/^\circ\text{C} + 273.15$
pressure of an ideal gas	$p = \frac{1}{3}\frac{Nm}{V}\langle c^2\rangle$
mean translational kinetic energy of an ideal gas molecule	$E = \frac{3}{2}kT$
displacement of particle in s.h.m.	$x = x_0 \sin \omega t$
velocity of particle in s.h.m.	$v = v_0 \cos \omega t$
	$= \pm \omega\sqrt{x_o{}^2 - x^2}$
electric current	$I = Anvq$
resistors in series	$R = R_1 + R_2 + \ldots$
resistors in parallel	$1/R = 1/R_1 + 1/R_2 + \ldots$
electric potential	$V = \frac{Q}{4\pi\varepsilon_o r}$
alternating current/voltage	$x = x_0 \sin \omega t$
magnetic flux density due to a long straight wire	$B = \frac{\mu_o I}{2\pi d}$
magnetic flux density due to a flat circular coil	$B = \frac{\mu_o NI}{2r}$
magnetic flux density due to a long solenoid	$B = \mu_o nI$
radioactive decay	$x = x_0 \exp(-\lambda t)$
decay constant	$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$

Answer **all** the questions in the spaces provided.

1 **(a)** State the principle of conservation of linear momentum.

....

....

....[2]

(b) Along a horizontal frictionless surface, ball A moves with speed *v* towards a stationary ball B as shown in Fig. 1.1. Ball A has mass 4.0 kg and ball B has mass 12 kg.

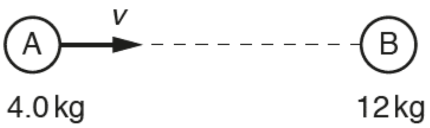

Fig. 1.1

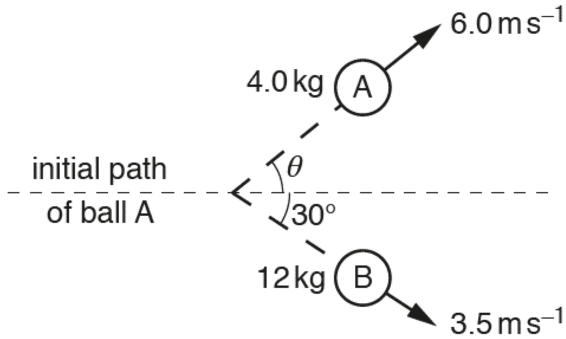

Fig. 1.2

The balls collide and then move apart as shown in Fig. 1.2.
Ball A has velocity 6.0 m s^{-1} at an angle of θ to the direction of its initial path.
Ball B has velocity 3.5 m s^{-1} at an angle of 30° to the direction of the initial path of ball A.

(i) By considering the components of momentum at right−angles to the direction of the initial path of ball A, determine θ.

θ = ...° [2]

(ii) Hence, determine the initial speed *v* of ball A.

v = ... m s^{-1} [2]

(iii) State and explain whether the collision is elastic or inelastic.

…………………………………………………………………………………………………..

…………………………………………………………………………………………….... [2]

[Total: 8]

2 A spring is kept horizontal by attaching it to points A and B, as shown in Fig. 2.1

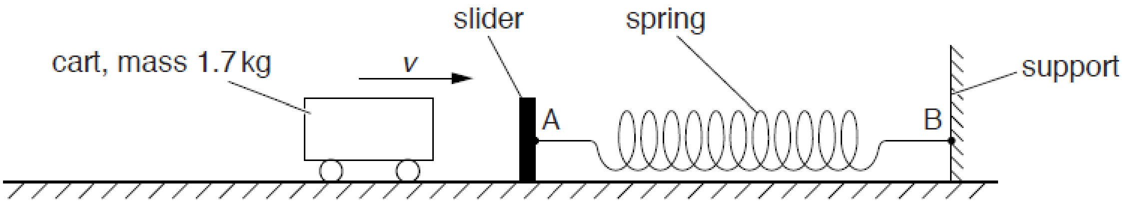

Fig. 2.1

Point A is on a movable slider and point B is on a fixed support. A cart of mass 1.7 kg has horizontal velocity *v* towards the slider. The cart collides with the slider. The spring compressed as the cart comes to rest.

The variation of compression *x* of the spring with force *F* exerted on the spring is shown in Fig. 2.2.

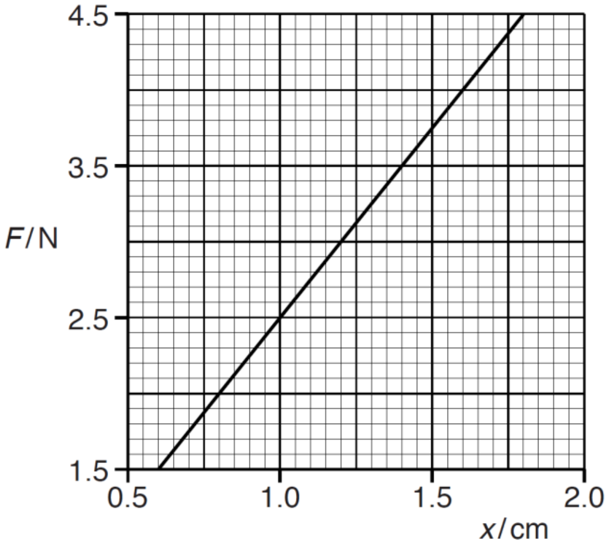

Fig. 2.2

Fig. 2.2 shows the compression of the spring for *F* = 1.5 N to *F* = 4.5 N. The cart comes to rest when *F* is 4.5 N.

(a) Use Fig. 2.2 to

(i) show that the compression of the spring obeys Hooke's law,

[2]

(ii) determine the elastic potential energy E_P stored in the spring when the cart is brought to rest.

E_P = ……………………………J [2]

(b) Calculate the speed v of the cart as it makes contact with the slider. Assume that all the kinetic energy of the cart is converted to the elastic potential energy of the spring.

speed = …………………. m s^{-1} [2]

[Total: 6]

3 A beam of unpolarised light is incident normally on a polaroid P as shown in Fig. 3.1. The polarised light after passing through polaroid P has amplitude A and intensity I_o.

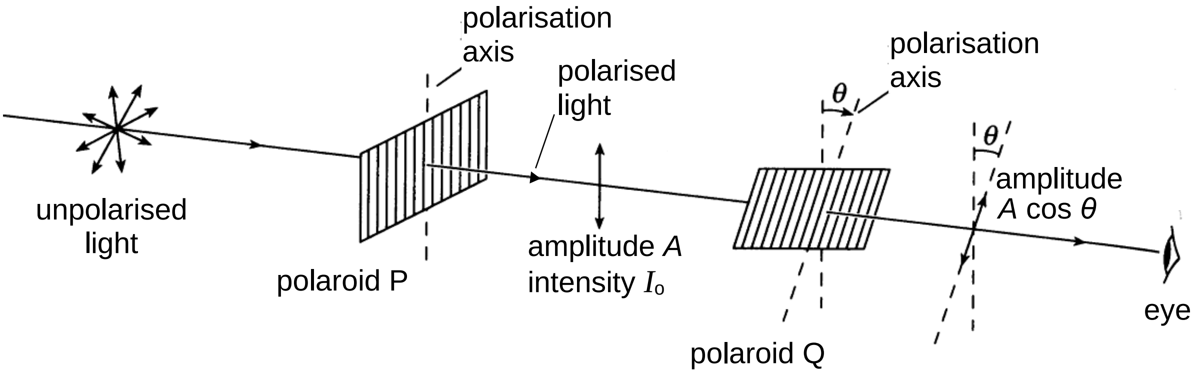

Fig. 3.1

The polarised light from polaroid P then passes through polaroid Q whose polarisation axis is inclined at an angle θ to the polarisation axis of polaroid P. This polarised light from Q has amplitude $A \cos \theta$.

(a) In Fig. 3.2, sketch a graph showing the variation of intensity of the polarised light from polaroid Q when it is rotated through $\theta = 0°$ to $\theta = 360°$.
Label all values on the axes.

Fig. 3.2

[2]

(b) Polaroid Q is now fixed with its polarisation axis kept at 90° to that of polaroid P.
A third polaroid R is then inserted between polaroids P and Q, with its polarisation axis inclined at an angle ϕ to the polarisation axis of polaroid P, as shown in Fig. 3.3.

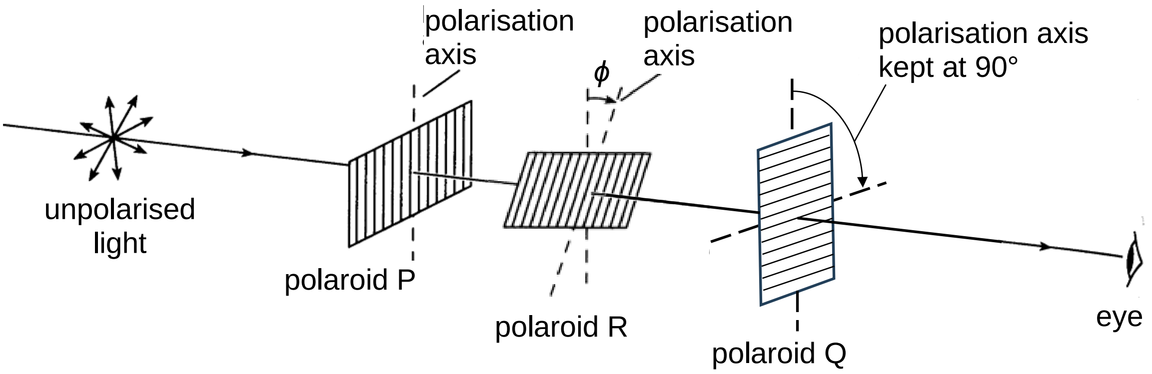

Fig. 3.3

(i) Calculate the intensity of the polarised light from polaroid Q in terms of I_o when ϕ is 30°.

intensity = …………………………… [2]

(ii) In Fig. 3.4, sketch a graph showing the variation of intensity of the polarised light from polaroid Q when polaroid R is rotated through ϕ = 0° to ϕ = 360°.
Label all values on the axes.

Fig. 3.4

[3]

(c) Explain why longitudinal waves cannot be polarised.

…………………………………………………………………………………………………...........
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………………………………………………………………………………………………......... [1]

[Total: 8]

4 **(a)** State two differences between progressive waves and stationary waves.

1. ………………………………………………………………………………………………...

………………………………………………………………………………………………………

2. ………………………………………………………………………………………………...

……………………………………………………………………………………………… [2]

(b) A source S of microwaves is placed in front of a metal reflector R, as shown in Fig. 4.1.

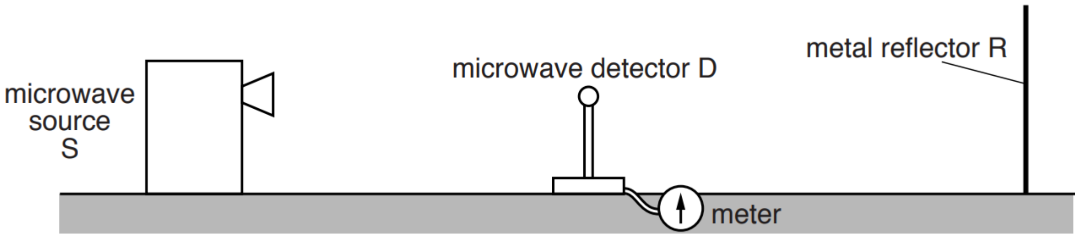

Fig. 4.1 (not to scale)

A microwave detector D is placed between R and S.

Describe

(i) how stationary waves are formed between R and S,

………………………………………………………………………………………………….....

………………………………………………………………………………………………….....

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…………………………………………………………………………………………….... [3]

(ii) how D is used to show that stationary waves are formed between R and S,

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……………………………………………………………………………………………………..

…………………………………………………………………………………………….... [2]

(iii) how the wavelength of the microwaves may be determined using the apparatus in Fig. 4.1.

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…………………………………………………………………………………………….... [2]

(c) The metal reflector R in **(b)** is replaced by another microwave source P which is in phase with source S, as shown in Fig. 4.2.

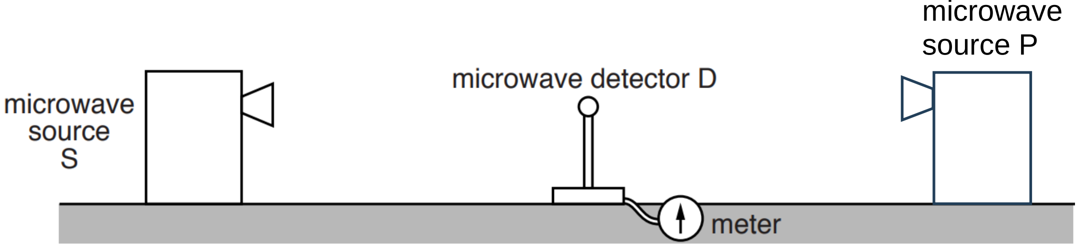

Fig. 4.2 (not to scale)

State and explain the reading of the detector D when it is positioned equidistant from the two sources.

....

....

.... [2]

[Total: 11]

5 **(a)** Two small charged metal spheres A and B are situated in a vacuum. The distance between the centres of the spheres is 12.0 cm, as shown in Fig. 5.1.

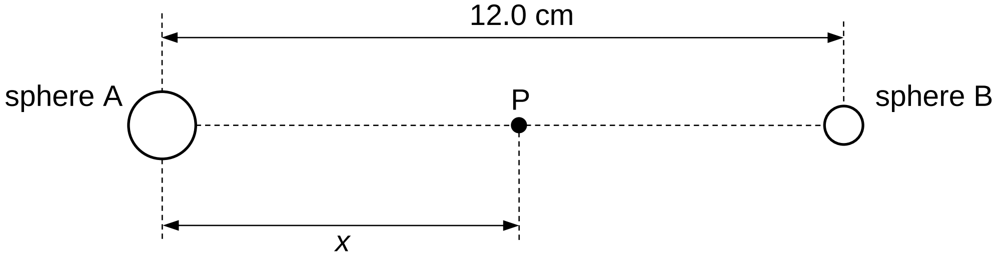

Fig. 5.1

The charge on each sphere may be assumed to be a point charge at the centre of the sphere. Point P is a movable point that lies on the line joining the centres of the spheres and is distance x from the centre of sphere A.

The variation with distance x of the electric field strength E at point P is shown in Fig. 5.2.

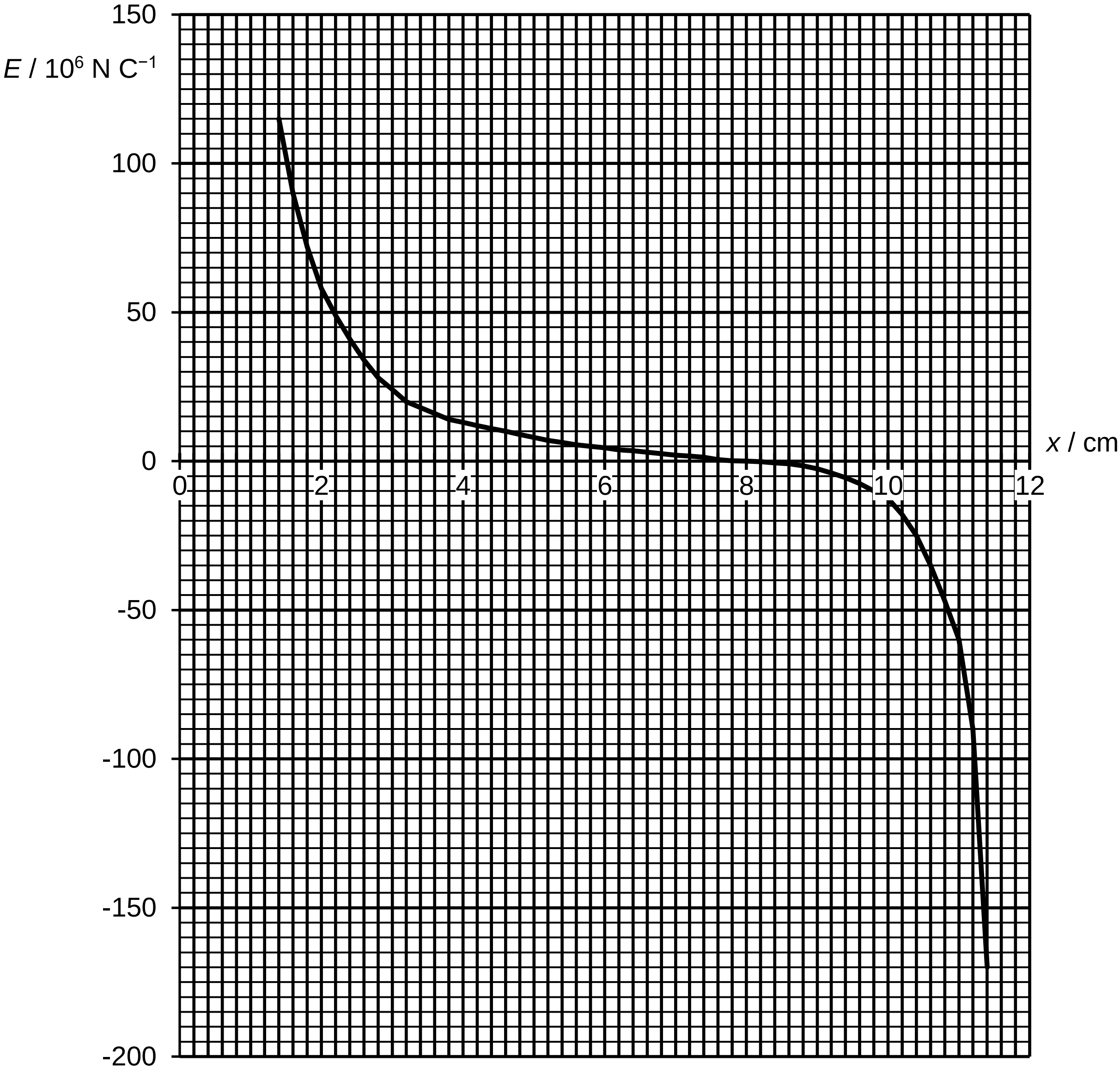

Fig. 5.2

(i) Explain whether the charges have the same, or opposite, signs.

……………………………………………………………………………………………….................

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…………………………………………………………………………………………….... [2]

(ii) Determine the ratio $\dfrac{\text{charge on sphere A}}{\text{charge on sphere B}}$.

Explain your working.

ratio = ………..……………….[3]

(b) Two long parallel plates are set a distance of 5.0 cm apart in vacuum as shown in Fig 5.3. The top plate is at a potential of –200 V and the bottom plate is at a potential of –100 V.

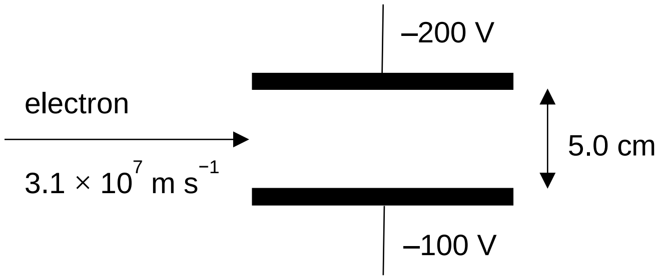

Fig. 5.3

An electron is projected horizontally at a speed of 3.1×10^7 m s^{-1}, mid-way between the plates.

(i) Determine the magnitude and direction of the electric field strength.

magnitude = ………………………N C^{-1} [1]

direction = …………………………[1]

(ii) Determine the magnitude of the acceleration of the electron.

magnitude of acceleration = ………………………m s^{-2} [2]

(iii) Determine the change in potential energy of the electron from the point of entry until it reaches one of the plates.

change in potential energy = ……………….. J [2]

[Total: 11]

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6 A small coil is positioned so that its axis lies along the axis of a large bar magnet, as shown in Fig. 6.1.

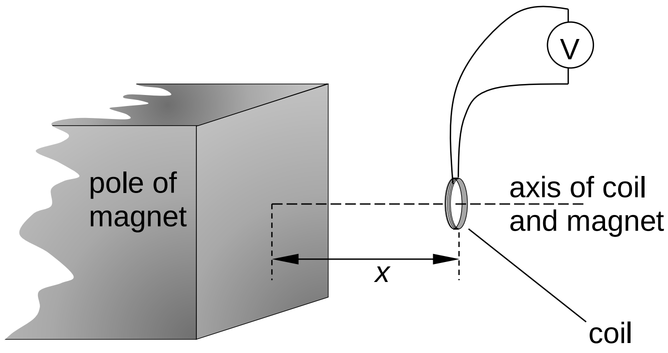

Fig. 6.1

The coil has a diameter of 5.3 mm and contains 180 turns of wire. The ends of the coil are connected to a voltmeter.

The average magnetic flux density B through the coil varies with the distance x between the face of the magnet and the plane of the coil as shown in Fig. 6.2.

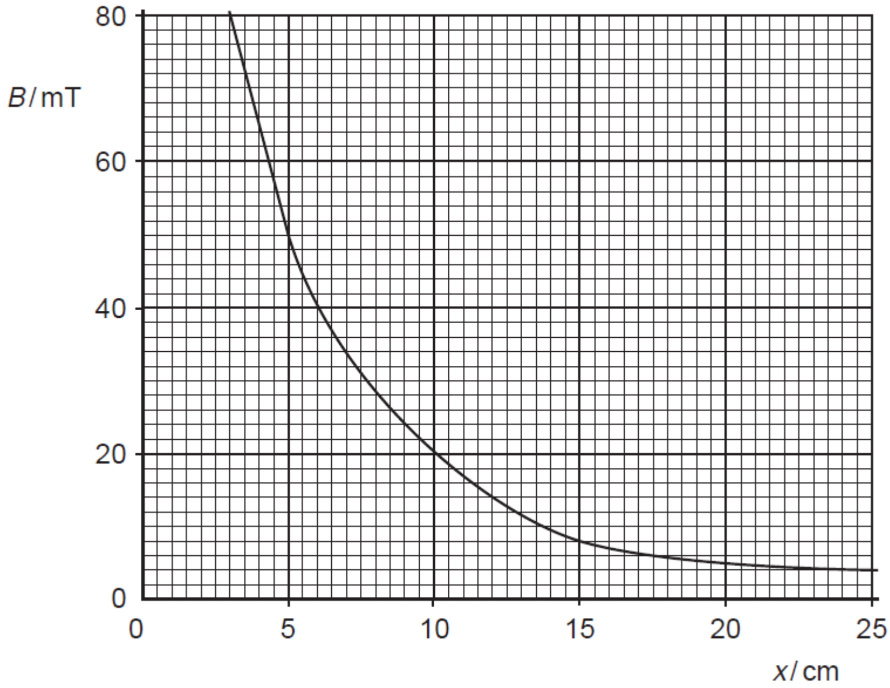

Fig. 6.2

The coil is initially 5.0 cm from the face of the magnet.
It is then moved at constant speed along the axis of coil and magnet to x = 20 cm in a time of 0.30 s.
As the coil is being moved, a deflection is observed in the voltmeter.

(a) Determine the average induced e.m.f induced in the coil.

e.m.f = …………………….... V [3]

(b) The voltmeter is now replaced with a resistor and the coil is again moved away from the magnet at constant speed. As the coil moves, thermal energy is transferred in the resistor.

Use laws of electromagnetic induction to explain the origin of this thermal energy.

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[Total: 6]

7 **(a)** A photocell may be used to demonstrate the photoelectric effect. Fig. 7.1 shows a photocell connected to a circuit.

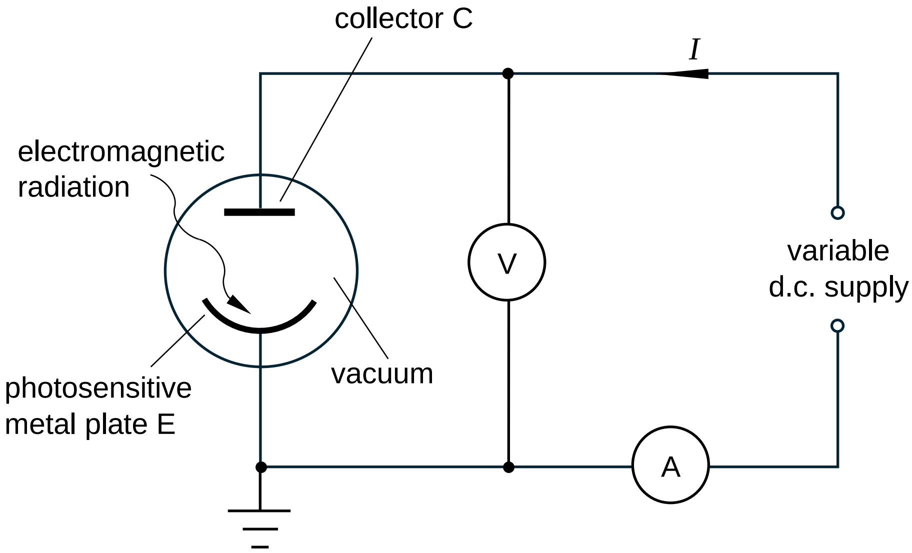

Fig. 7.1

The photocell consists of two metal plates E and C. The metal plate E is sensitive to electromagnetic radiation. The plate E is illuminated by electromagnetic radiation of frequency greater than the threshold frequency. Photoelectrons are emitted towards the collecting plate C. A sensitive ammeter measures the photoelectric current.

Fig. 7.2 shows the variation with potential difference V of the photoelectric current I for radiation of a particular intensity.

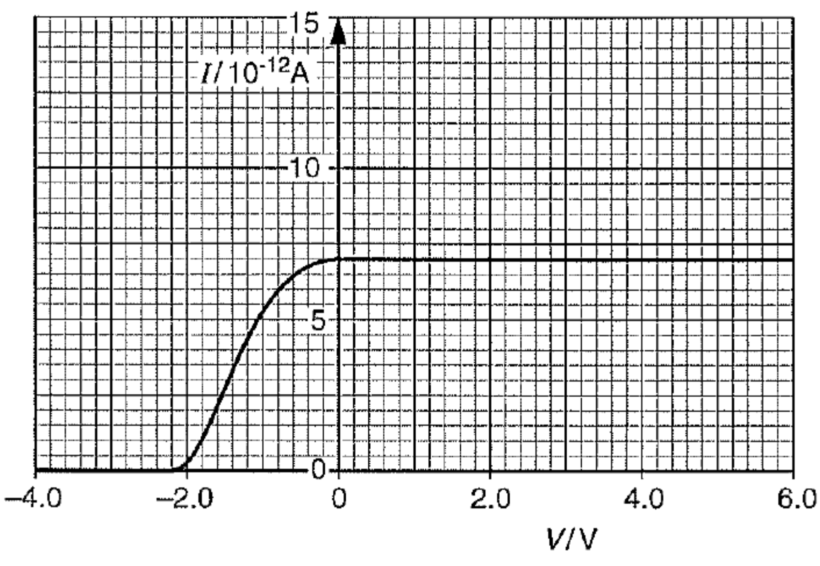

Fig. 7.2

(i) With reference to photoelectrons, explain the significance of the sloping section of the graph for negative values of potential difference.

……………………………………………………………………………………………........

……………………………………………………………………………………………........

……………………………………………………………………………………………........

…………………………………………………………………………………………….[2]

(ii) Use Fig. 7.2 to determine the maximum speed v_{max} of the photoelectrons. Explain your working clearly.

v_{max} = …………….…………... m s^{-1} [3]

(iii) The intensity of the electromagnetic radiation is halved but its frequency is kept constant.
On Fig. 7.2, sketch a graph to show the new I−V characteristic. [2]

(b) In a particular laboratory experiment, a zinc plate has a work function of 5.8×10^{-19} J. Ultraviolet light of wavelength 120 nm is incident on the zinc plate. A photoelectric current I is detected.

In order to view the apparatus more clearly, a second lamp emitting light of wavelength 450 nm is switched on. No change is made to the ultraviolet lamp.

Using appropriate calculations, state and explain the effect on the photoelectric current of switching on this second lamp.

……………………………………………………………………………………………………

……………………………………………………………………………………………………

…………………………………………………………………………………………....... [3]

[Total: 10]

8 Read the passage below and answer the questions that follow.

X-ray and magnetic resonance imaging (MRI) are some modern imaging techniques in medicine that uses externally placed devices to obtain diagnostic information from underneath the skin.

A modern form of X-ray tube used to obtain the internal body structure of a patient is shown in Fig. 8.1 (not to scale).

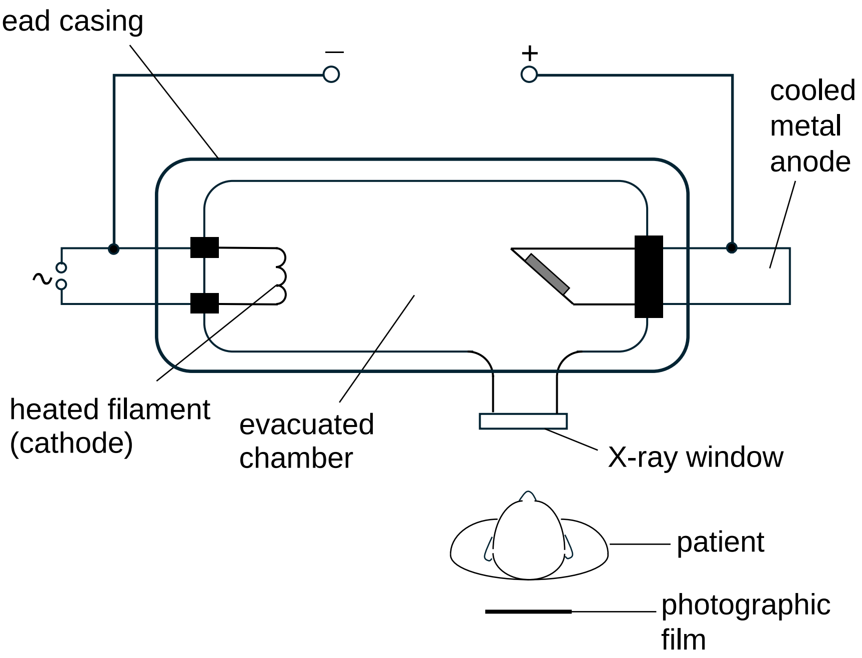

Fig. 8.1

In the X-ray tube, electrons emitted from the heated filament are accelerated through a large potential difference towards the metal anode, producing X-rays. The filament at the cathode is typically made of thin tungsten wire. The X-rays produced are controlled and directed to leave the X-ray tube via a window. As the X-ray beams pass through the patient, varying degree of X-ray gets absorbed, depending on the composition of the body. The remaining X-rays then reach the photographic film where a contrast image of the internal body structure is obtained. Good contrast is achieved if there is a clear difference in the blackening of the photographic film as the X-ray passes through and gets absorbed by different types of tissue in the patient. Typically, a good contrast is obtained when the ratio of the transmitted X-rays between different body parts has an order of magnitude of at least 1.

The gradual decrease in intensity of a beam of X-ray as it passes through matter is represented by the equation

$$I = I_0 e^{-\mu x}$$

where I_0 is the initial intensity, x is the thickness of the material, I is the transmitted intensity and μ is the absorption (attenuation) coefficient. Fig. 8.2 shows the absorption (attenuation) coefficient of some matter with 30 keV X-rays.

matter	μ / cm^{-1}
blood	0.41
bone	2.46
brain	0.41
muscle	0.40

Fig. 8.2

Magnetic resonance imaging (MRI) is another imaging technique that relies on the fact that some atomic nuclei behave like tiny magnets in an external magnetic field.

In MRI, it is usually the nuclei of hydrogen atoms that are studied, since hydrogen atoms are present in all tissues. The hydrogen nucleus contains only one proton, and it has a property called spin. When a very strong external magnetic field is applied, the magnetic axis of a hydrogen nucleus does not align itself directly along the external magnetic field, but rotates around it, just like the axis of a spinning top, as shown in Fig. 8.3. This rotation or gyration action is known as precession.

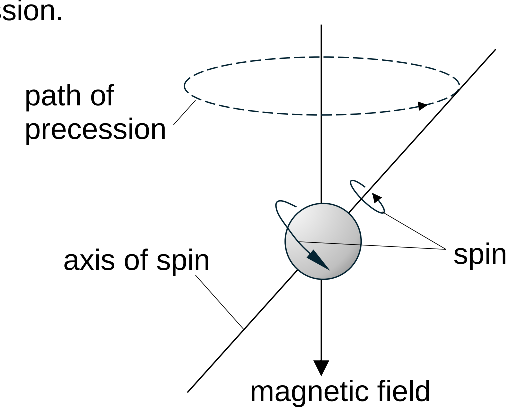

Fig. 8.3

The angular frequency of precession is called the Larmor frequency, ω_0, and depends on the individual nucleus and the magnetic flux density B_0 of the magnetic field.

$$\omega_0 = \gamma B_0$$

The quantity γ is the gyromagnetic ratio for the nucleus and is a measure of its magnetism. For hydrogen nucleus, the ratio is approximately 2.68×10^8 rad s^{-1} T^{-1}.

Fig. 8.4 shows an MRI scanner comprising three set of coils: main coil, gradient coil and radio frequency (RF) coil. The main coil is a solenoid that is 2.2 m long and 1.0 m in diameter. It is made of superconducting wire that carries a current of 750 A and produces an external magnetic field of 1.5 T. To achieve superconductivity, the main coil is cooled using liquid helium to a temperature slightly below the boiling point of helium at 4.2 K.

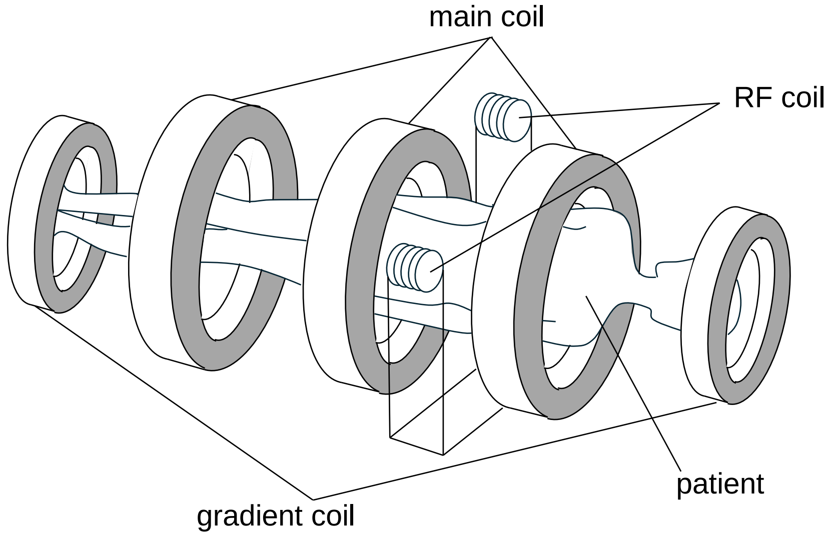

Fig. 8.4

A set of gradient coils produces an additional external magnetic field that alters the magnitude of the magnetic flux density across the length, depth and width of the patient. A radio frequency (RF) coil transmits RF pulses into the body that causes nuclear magnetic resonance of the hydrogen nuclei.

When the RF coil is switched off, the hydrogen nuclei relax and release energy in the form of RF waves that can be detected. The rate of relaxation of the nuclei follows an exponential decay curve. This can be characterised by a spin-lattice relaxation time, *t*.

Fig. 8.5 shows *t* of some matter in a magnetic flux density of 1.5 T.

matter	*t* / ms
blood, oxygenated	1200 – 1600
bone	< 100
brain, gray matter	900 – 1300
brain, white matter	600 – 800
muscle	900 – 1000

Fig. 8.5

Different tissues can be distinguished by the different rates at which they release energy after they have been forced to oscillate.

(a) Explain the principles of production of the continuous X-ray spectrum.

....

....

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....

....

....[3]

(b) Suggest a reason why tungsten is used for the filament at the cathode of an X-ray tube.

....

....[1]

(c) A cross-section of a model arm is shown in Fig. 8.6.
In an investigation into the absorption of X-ray radiation in the model arm, parallel X-ray beams of 30 keV are directed along the line MM and along the line BB.

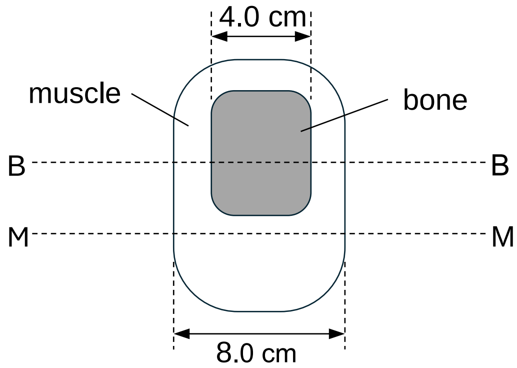

Fig. 8.6

(i) Calculate the ratio

$$\frac{\text{intensity of transmitted X-ray beam from model}}{\text{intensity of incident X-ray beam on model}}$$

for a parallel X-ray beam directed along the line

1. MM,

ratio = ………………………………… [2]

2. BB.

ratio = ………………………………… [3]

(ii) Explain whether the X-ray image obtained has good contrast.

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

…………………………………………………………………………………………………... [2]

(d) MRI scanning typically takes 30 minutes to more than 1 hour. Explain why MRI is particularly suitable for producing detailed images of the brain compared to X-ray, despite the longer duration compared to X-ray.

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…………………………………………………………………………………………………...

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…………………………………………………………………………………………………...[2]

(e) State one disadvantage of using MRI.

…………………………………………………………………………………………………...

…………………………………………………………………………………………………...[1]

(f) Determine the number of turns in the main coil of the MRI scanner.

number of turns = ………….………….…..... [2]

(g) Determine the frequency of the pulse of the RF waves required to cause nuclear magnetic resonance of hydrogen nuclei in the MRI scanner.

frequency = ……….…………….... Hz [2]

(h) During an MRI procedure, a small segment of the main coil loses its superconductivity, and the resistance of the wire suddenly increases to 0.0045 Ω. An increase in temperature of the main coil occurs, causing liquid helium to rapidly vaporise. The latent heat of vaporisation of helium is 21 kJ kg^{-1}.

Determine the initial rate of vaporisation of liquid helium.

initial rate of vaporisation = ………………………….. kg s^{-1} [2]

[Total: 20]